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Tillage and cover crop effects on productivity, soil properties, and nitrate leaching

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Introduction

Nitrate (NO_3-N) pollution in rivers and streams from surface runoff and leaching to groundwater is a major problem across the United States (Nolan et al., 1998; Burkart and James, 1999; USGS, 2001) and Iowa as well. Previous work (Keeney, 1989; Burkart and James, 1999; Schilling and Libra, 2000) indicates that agricultural land use has been identified as the main contributor to the NO_3-N load in our rivers and streams. The high mobility of NO_3-N makes it readily available for leaching through the soil profile, especially during the periods when no active plant growth is taking place between harvest and planting (in absence of a cover crop) to capture residual soil nitrate. By implementing management practices that deter NO_3-N leaching we may also reduce the NO_3-N load in rivers and streams.

Tillage practices greatly alter the physical and biological properties of the soil. The effects that occur from these tillage practices are greatly influenced by the type of landscape, soil characteristics (i.e., drainage class, slope, soil texture, etc.), crop rotation, and type of tillage practices. Many states have been urging farmers to practice conservation tillage due to its ability to minimize surface runoff and soil erosion. Conservation tillage systems and extended crop rotations offer an alternative to minimize nitrate leaching. However, some researchers believe this will lead to an increase in NO_3-N leaching, due to improvement of infiltration in conservation systems (i.e., no-tillage system). In a study conducted by Tyler and Thomas (1977), higher volumes of leachate and NO_3-N and Cl^- masses in leachate collected 40 inches below the soil surface were associated with no-tillage than with conventional tillage. Another study conducted by Randall and Bandel (1987) showed that there was greater downward movement of Br^- tracer applied to no-tillage plots as opposed to conventionally tilled plots. Conflicting results have been observed in other studies. Kanwar et al. (1985) observed more NO_3-N leached below 60 inches in conventional tillage than in no-tillage using rainfall simulations on a loam soil in Iowa. Drury et al. (1993) also found that tile drainage volume and NO_3-N mass were higher in conventional tillage than in no-tillage.

The advantages of conservation tillage systems along with extended crop rotations in improving soil biological, physical, and chemical properties, present a challenge concerning both surface and ground water quality. The inclusion of cover crops with conservation systems presents very attractive alternatives to achieve the improvement of both water and soil quality. With increasing concerns in the areas of soil erosion and groundwater quality, significant interest has been developed to examine the interaction of tillage systems and cover crops on both soil and water quality parameters. Cover crops greatly increase the amount of residue on the soil surface. In return, this reduces the amount of surface runoff due to interception of rain and the slowing of water flow. In addition to affecting surface residue cover, a winter rye cover crop, for example, can also influence the dynamics of N cycling (Ditsch and Alley, 1991). A winter rye cover crop following corn in a no-till system reduced spring NO_3-N accumulation in soil due to N uptake by rye (Ditsch et al., 1993; Shipley et al., 1992). To evaluate the interaction of tillage and cover crops, such as rye, on crop performance and soil and water quality parameters, a field and a greenhouse study were conducted in 2007 and 2008. The following questions were developed to be answered by this research:

- Is there an interaction effect of tillage practice and cover crop on NO_3-N transport through the soil profile?
- How does the interaction between tillage and cover crop affect crop performance and selected soil physical properties?

Materials and methods

Field study

The field study was conducted on the Iowa State University Marsden research farm near Ames. The soils are Nicollet loam (fine-loamy, mixed, mesic, Aquic, Hapluduolls) and Webster silty clay loam (fine-loamy, mixed, mesic, Typic, Haplaquolls). The study consists of 5 tillage systems; no-tillage, strip tillage, chisel plow, deep rip, and moldboard plow. All tillage treatments were conducted in the fall following the harvest of the previous crop. Nitrogen was applied in the form of 32% ammonium nitrate in the spring. The experimental design used in this study was a randomized complete block with split plot arrangement. Plot dimensions were 90 ft long and 30 ft wide. The plots were split into two halves with the same tillage treatment. A corn-corn-soybean rotation and a corn-soybean rotation were designated to each half. The half going into soybeans received a cover crop, and the half that will be planted with corn received no cover crop.

The cover crop used for this study was cereal rye. Rye is a common cover crop for Iowa. It is known to be a good scavenger of nutrients throughout the soil profile, and its extensive root system allows it to work against compaction in heavily tilled soils. The rye was drilled to a depth of 1 inch at a rate of 150 lbs./acre after harvest took place in October of 2007 and 2008.

Soil measurements and data collection

Soil samples were collected at five different depths with 6 inch increments for soil carbon, total N, bulk density, soil pH, soil nitrate, and microbial biomass analyses.

In addition, soil samples were collected from the top 6 inches to determine soil aggregate stability. The samples were collected by using a golf course hole cutter of 4-inch diameter. The aggregate stability was determined using the wet method after soil samples were passed through an 8-mm sieve. A 100 g of the soil sample was placed on a nest of sieves in the following order from top to bottom: 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm.

The water infiltration rate was measured using a Cornell Sprinkle Infiltrometer (Rain Simulator) (Cornell University, Ithaca NY) (Ogden et al., 1997). This system consists of a portable rainfall simulator placed on a single 24.1 cm (9.5 in) inner diameter ring inserted 7 cm (3 in) into the soil. The ring is equipped with an overflow tube to determine the time to runoff and runoff rate. Rainfall simulator intensity rates of 0.4 to 0.5 cm (0.15 to 0.20 in) min^{-1} were used. Every three minutes, runoff was measured until steady infiltration occurred. Water infiltration (i) was calculated by using the following equation:

$$i = r - rot.$$

Where r is rainfall intensity and rot is surface runoff

Nitrate leaching

Potassium Bromide was used as a tracer in both years to examine the effect of cover crop on Br^- movement since Br^- has similar chemical properties as nitrate. The Br^- was applied to cover and non-cover crop treatments of each tillage system and used as a tracer. Soil water samples were collected to measure both bromide and nitrate concentrations leached after each rainfall event from each tillage system at a 48-inch soil depth using a suction tube with a porous ceramic cup. Thirty grams of KBr (potassium bromide) was applied evenly to the soil surface of both cover crop and non-cover crop treatments of 3 by 3 ft area around each suction tube.

The water samples were collected from each suction tube in plastic nalgene bottles and placed in a cooler. The water samples were frozen if Br^- and NO_3-N analyses were not done immediately.

Greenhouse study

A greenhouse study was conducted to complement the field study. Undisturbed soil columns for the greenhouse study were taken from previous study plots at the Iowa State University Northeast Research and Demonstration farm near Nashua (43.0º N, 92.5º W) at a depth of 17 inches. The undisturbed soil samples were collected by driving galvanized metal cylinders with an inside diameter of eight inches into the soil using a Giddings soil probe. The cylinders were 26 inches tall. There was nine inches of space from the top of the metal column to the soil surface. The undisturbed soil columns were collected from no-tillage (NT), strip-tillage (ST), and chisel plow (CP) plots. Eight soil columns were collected from each tillage system from one plot of the corresponding tillage system.

Three of the soil columns, one from each tillage treatment, were used for lab analysis. The experiment was set in a randomized complete block design with three replications. For each tillage treatment, three soil columns were planted with a cereal rye cover crop and three soil columns without cover crop, and they were randomly placed within each replication. The cereal rye was hand planted at a rate of 150 lbs./acre. Distilled water was applied to both the cereal rye treatment and the non-cover crop treatment for growth purposes. After rye emergence and prior to water application for leaching, excess soil was packed around the sides of the columns to prevent preferential flow along the column walls. After conditioning the columns was complete, 1.026 g of KBr was dissolved into 500 ml of water and applied evenly to the soil surface. Ammonium nitrate equivalent to 130 lb N/acre was also applied to all treatments. Deionized water was applied once a week to all soil columns (1000 mL). The water was applied to the soil surface using 250-mL nalgene bottles.

Measurements of water volumes, times and dates were recorded. Leachate samples were collected during the leaching period for nitrate and Br^- analyses. The cover crop was terminated when it reached a height of 24 inches.

Results and discussions:

Corn yield response following a rye cover crop

Corn yields after cover crop from different years and fields are summarized in Fig. 1. Average corn yield difference with and without a rye cover crop following soybean was about 4 bu/acre. Most of the larger corn yield differences were in the early years of these two experiments, especially Kelly 2002. From other experiments, we know that corn population can be affected by a rye cover crop and this may be the cause of reduced yield in some years. We have adjusted our corn planting rates from 31,000-32,000 seeds/ac to 34,000/35,000 seeds/acre and this seems to have helped. We also try to spray the rye cover crop with glyphosate 10-14 days before planting corn. Earlier work showed that this also helps. We do not have much data for a rye cover crop in continuous corn (Tom Kaspar, 2009).

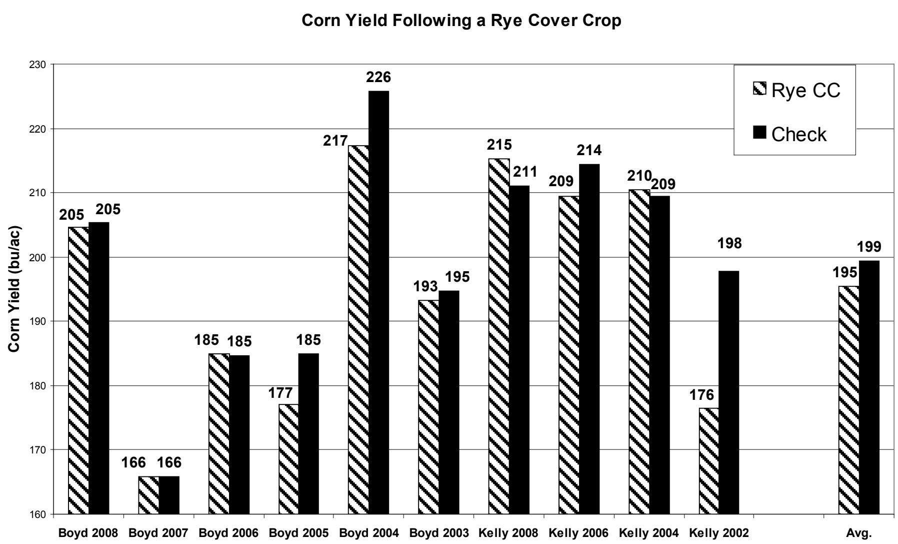

Figure 1. Corn yield response following a rye cover crop. (Tom Kaspar, 2009).

Cover crop effect on water use

Cover crop shows considerable effect on soil moisture conditions. Results from greenhouse leaching study (Figs. 2a and b) summarize water volume collected at different times from cover crop and non-cover crop treatments. Under no-cover crop treatment the leached water volume was on average between 60 and 80% of applied water during leaching events, while the amount of leached volume of cover crop treatment was the highest during the first leaching period, approximately 70% of the applied water, and then declined sharply to approximately 20%. These differences in the amount of leached water volume reflect the effectiveness of cover crop in extracting moisture from the soil profile, especially in the absence of a crop growing in soil. This mechanism is critical in reducing soil nitrate loss to groundwater. The development of the cover crop and its extensive root system leads to significant water uptake, which contributes to increase soil storage capacity for any additional water or rainfall. The effectiveness of cover crop in reducing water leaving the soil profiles depends on good establishment of cover crop after harvest.

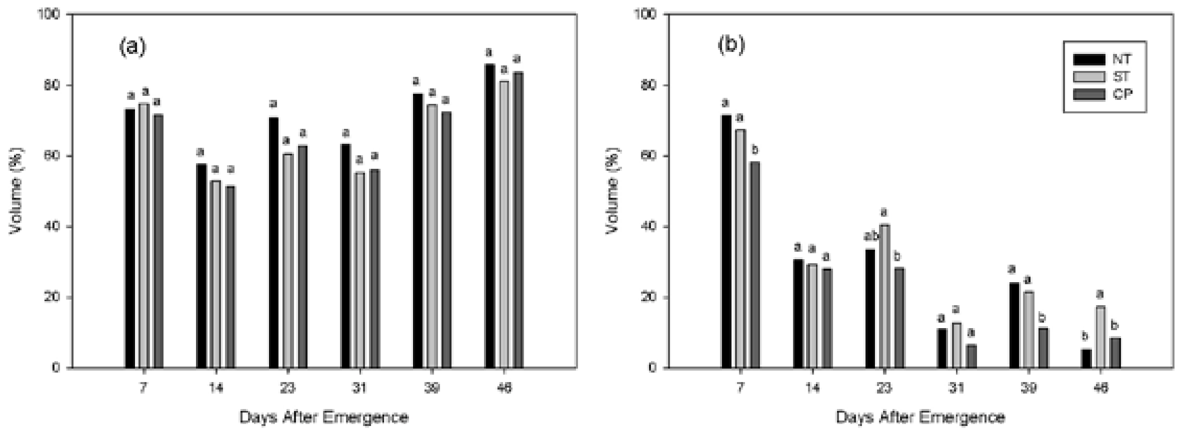

Figure 2. Volume of water leached as a percent of applied water for each tillage system during each leaching event under (a) no-cover crop treatment and (b) cover crop treatment of greenhouse study 2007-2008.

Cover crop and nitrate leaching

Nitrate leaching is generally affected by soil moisture status and volume of water leaving the soil profile. The effect of cover crop on soil moisture and water flux from the soil profile was significant as shown in Fig. 2a and b. These differences in water flow will influence the amount of NO_3-N or Br^- leached from the soil profile as shown in Fig. 3a and b. The results show significant reduction in NO_3-N and Br^- concentration due to the growth of cover crop. Over time, leaching of NO_3-N was only 16% from cover crop treatment compared to 54% from non-cover crop treatment (Fig. 3c). Bromide leached at a similar rate to that of NO_3-N with 19% from cover crop and 47% from no-cover crop treatments (Fig. 3d). The trend of both NO_3-N and Br^- leaching shows the effectiveness of cover crop in reducing the loss of nitrate from the soil profile. These results show the effect of cover crop in using soil moisture during the time when no active crop root system is growing, early in the spring, when significant amounts of water will be moving through the soil profile.

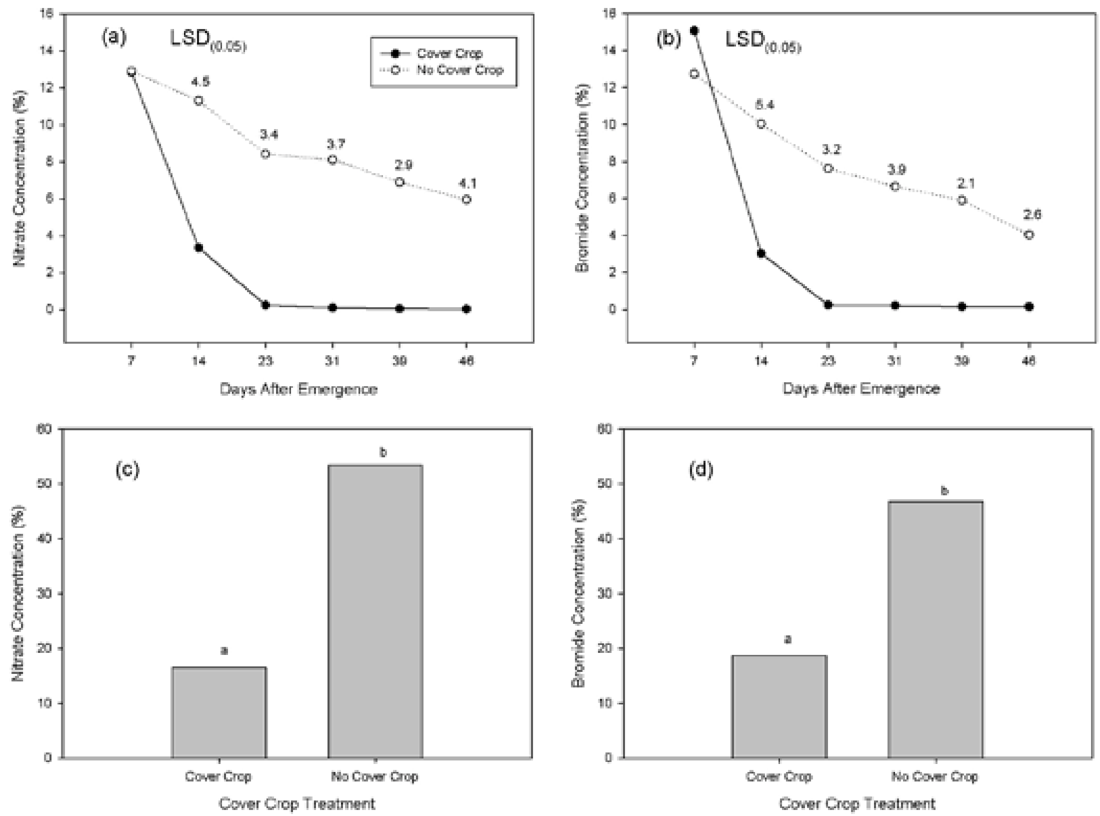

Figure 3. Nitrate and Bromide percent losses due to leaching in greenhouse study under cover and no-cover treatments (a) NO_3-N loss (b) Bromide loss, (c) total percent loss of NO_3-N and (d) total percent of Bromide loss over the period of the study. Differences between treatments concentrations within each leaching event greater than the LSD value are significantly different at p=0.05.

Effect of cover crop on soil physical properties

Some of the benefits of cover crop are the improvement of soil structure, which leads to an improvement of water infiltration. Field results in Fig. 4a and b show the effect of cover crop in improving infiltration rate of all tillage systems. Generally, cover crop increased the initial water absorption or dry soak with all tillage systems. In both cover and no-cover crop treatments, the moldboard plow plots had significantly lower infiltration rates compared to the rest of the tillage systems. These changes in water infiltration are the result of the cover crop's effect in improving soil structure, soil porosity, and water movement due to its intensive fibrous root system. The steady state of water infiltration, where the soil is under saturated conditions, shows a great difference between cover and no-cover crop treatments (Fig. 4c). The significant effect of cover crop on water infiltration rate is very evident within all tillage systems.

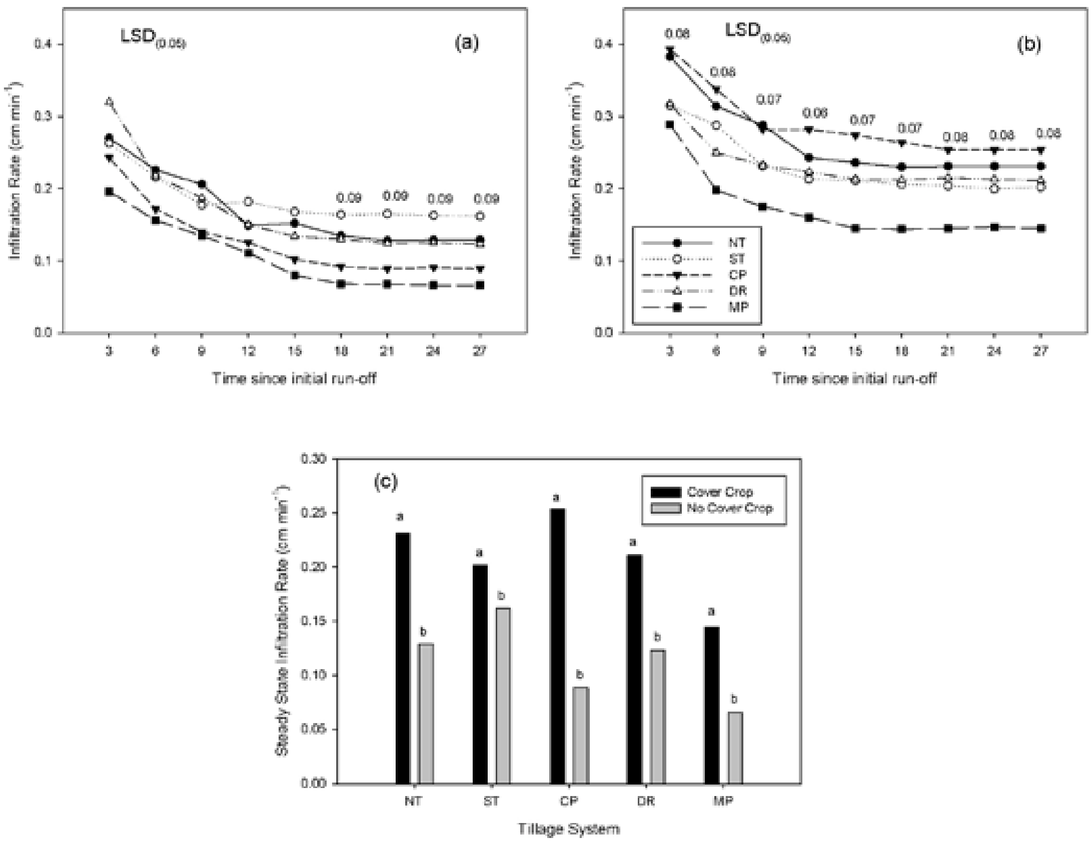

Figure 4. Infiltration rate of five tillage systems over time under (a) no-cover crop treatment, (b) cover crop treatment, and (c) infiltration at steady state of five tillage systems of cover and no-cover crop treatments. Differences between treatments' infiltration rates within each time period greater than the LSD value are significantly different at p=0.05.

Potential cover crop contribution to total soil carbon and nitrogen

Another value of cover crop is the potential of total carbon and N input from both above- and below-ground (root system) biomasses. Figures 5a and b, summarize potential total C and N input from both aboveground and root system biomasses in soil. Regardless of tillage system, the contribution of aboveground biomasses and root system to soil organic matter at the time of killing the cover crop was approximately 250 lb total C/acre and 75-130 lb total C/acre, respectively. In addition, there was 19-24 lb total N/acre from aboveground biomass and 3-7 lb total N/acre from the root system. These contributions are significant in improving soil qualities such as soil structure, infiltration, aggregate stability, etc. The amount of total C and N added to the soil by the cover crop could be affected by cover crop establishment, stand density, and the timing of termination early in the spring. Above ground biomass left on the field after killing the cover crop can contribute to soil protection from water erosion in addition to soil total C and N benefits.

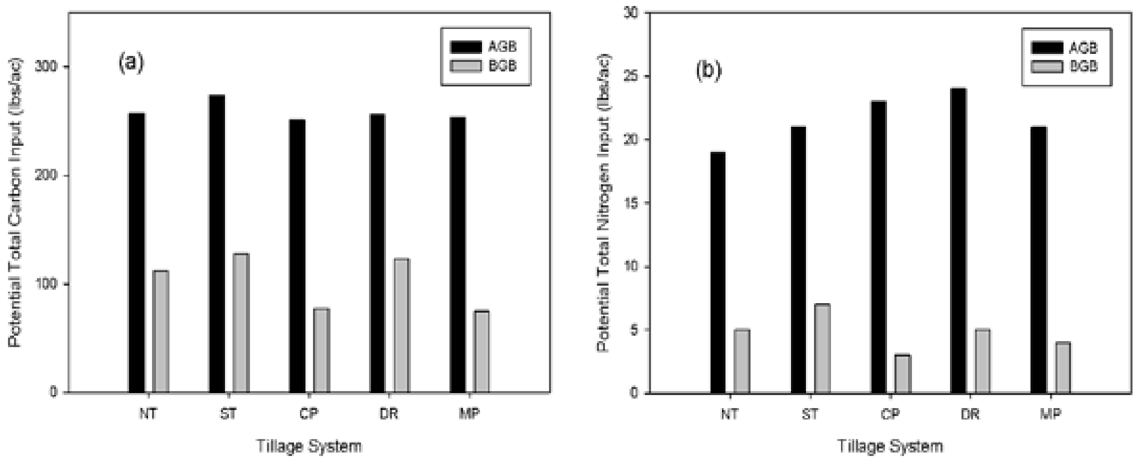

Figure 5. Cover crop potential (a) total carbon input and (b) total nitrogen input from both above-ground biomass (AGB) and below-ground biomass (BGB).

Summary

Cover crop has significant advantages in improving soil quality and reducing nitrate leaching regardless of the tillage system. The results of this research and others demonstrate the impact of cover crop in reducing the amount of water leaving the soil profile, which in return caused less nitrate leaching. In addition to the improvement in retaining nitrate in the soil profile under cover crop, significant improvement in soil quality and carbon input from cover crop was observed. There was some yield decline in corn after cover crop of about 4 bu/acre after a rye cover crop, but there was no yield reduction in soybean yield following a rye cover crop. However, corn yield reduction after cover crop improved over time.

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